

Dynamics of Zn between soil and plant in Northeast *Leymus chinensis* grassland

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Abstract: A study was conducted to determine the dynamic of Zn content between soil and plant in the natural protection zone of *Leymus chinensis* grassland in Changling County (44°30'–44°45'N; 123°31'–124°10'E), Jilin Province, China. Results showed that the total Zn content was lower, available Zn content had a moderate level in the soil, and the plants was not lack of Zn. During the growing season, content of total Zn and available Zn in soil showed a down-trend distribution along the soil profile. Content of total Zn had a significantly positive correlation with that of the organic matter, but it was negatively correlated to soil pH. Monthly dynamic of the average content of total Zn showed a “V” type curve in the growing season from May to August, and July was the nadir. The trend of the average content of available Zn was similar to the content of total Zn, but was down after August; Zn content variation in the organs and litter of *L. chinensis* was great, with the order of root>rhizome >leaf>stem>litter. The ratio of available Zn content in A layer versus B layer was more than 2 times that of the total Zn, which indicated that the soil of A layer had higher enrichment capacity of available Zn. The enrichment of Zn in the root of *L. chinensis* was 44.17 times as that in the soil. The absorbing intensity of root had a significantly negative correlation with the activity of Zn in the soil ($r=-0.8800$, $p<0.01$).

Keywords: *Leymus chinensis* grassland; Soil; Zn

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Introduction

Zn, as a necessary trace element for plant growth and a component of many enzymes, has very important physiological functions (Kabata 1992; Lindsay 1972). Higher or lower Zn levels can also limit the growth of plants (Zou 1985). The report of FAO (Food and Agriculture Organization of the United Nations) indicated that lack of Zn was a prevalent phenomenon in worldwide soil in 1967. Ten of the fifteen European countries had extremely low level of Zn in the soil, and the availability of Zn was rather low as well (Alina 1996). Almost every state in America had low level of Zn and sale of Zn fertilizer was the most among all microelement fertilizers. The reduction of crop caused by the lack of Zn is universal throughout the world. Scholars of many countries had reported the distributing rule of Zn in soil (Johanne 2002; Zeng 1998; Zhang 2002; Xu 2000), the effects of soil parent materials and environmental factors on Zn (López-Mosquer 2005; Zhnag 2002; Tao 1995) and the content and distribution of Zn in animals and plants (Keller 2003; Zheng 1996; Liu 1999). The Northeast grassland is vast in territory, which is an important base for grazing in China. Research in the past indicated that the content and validity of Zn were relatively low (Liu 1991; Wang 2002). Plants with the low Zn levels may reduce the productivity of the community. This paper will consider in detail the spatio-temporal dynamics of total Zn and available Zn in the soil of the *Leymus chinensis* community. Meantime, the effects of environmental factors on Zn validity, and the distribution of Zn in the *L. chinensis* and litter had been

studied firstly in detail. This result will provide a scientific basis for further studying the change of nutrition elements in the grassland ecosystem.

Materials and methods

Site description

The study area is located in the Natural Protection Zone of *L. chinensis* grassland in Changling County in the western part of Jilin Province (44°30'–44°45'N; 123°31'–124°10'E), with a temperate semi-arid monsoon climate. According to climate data over the past 30 years, the annual mean air temperature is about 4.9°C. Annual precipitation ranges from 350 mm to 450 mm, 86% of which concentrates on between June and September. Annual transpiration is about 1 600.2 mm, which is 3.5 times higher than the annual precipitation. This region is an alluvial plain formed by natural geological functions, and the soil type is chernozem. Most of them have a high saline content. The zonal vegetation is meadow steppe, and *L. chinensis* is the most important type in the community, with a density level of 917 tillers·m⁻², and its biomass accounts for 90% of all plant species. *Calamagrostis epigeios*, *Chloris virgata*, *Puccinellia tenuiflora* and *Suaeda glauca* etc. are other companion species found in the study area.

Methods

Plants sample

The hypsography of sample plots is flat; micro-landform, soil condition and vegetation are homogeneous; and the community of *L. chinensis* is represented as well. Sampling time was about the tenth day of every month from May to October, 2001. Six random sampling plots (25 cm×25 cm) were selected. Plants were cut close to the ground in the plots and the litter of *L. chinensis* was picked out. Stems, leaves and spikes of *L. chinensis* were divided separately. Soil poles with a size of 25 cm×25

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cm×45 cm were dug out just in the plots above (Below 45 cm the weight of root is less than 10%, so soil below 45 cm is ignored). The white roots and rhizomes of *L. chinensis* were washed through a 40 mesh sieve, and picked out and washed further, then dried in the oven at 65°C.

Soil sample

The first layer of soil was sampled at 0–1 cm, and six additional layers of soil were collected every 10 cm down the soil profile from 1-cm deep in the above referenced plots. Meantime, layers A (0–30 cm) and B (30–60 cm) of soil was sampled in the same plots. Samples were air-dried in a room, then the dried soil was smashed and put through the 100 mesh sieve.

Determinations of the physical and chemical indexes of soil, and the contents of Zn in plants and soil

Soil pH was measured by a SPM-10 digital pH meter. The organic substance of soil was measured by potassium dichromate method. Total Zn liquids of plants and soil were prepared by nitration. Available Zn was extracted by DTPA and the content of Zn was measured by a WFX-F2 atom absorbing spectrophotometer.

Results and analysis

Spatio-temporal dynamic of total Zn content in the soil

From May to October, the change trends of total Zn content were similar to the change of soil profile. Content of total Zn showed a downtrend from the soil depth of 0–1 cm to 40–50 cm, and an uptrend at the 50–60 cm layer (Fig. 1).

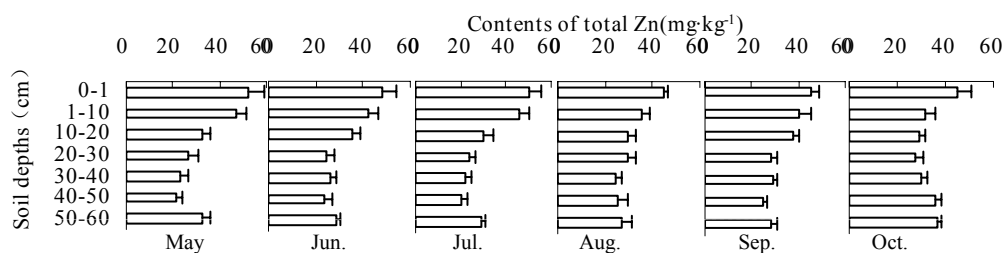


Fig.1 Spatio-temporal dynamic of total Zn content in the soil

Average content of total Zn in the soil was 33.70 mg·kg⁻¹, 31.79 mg·kg⁻¹, and 31.23 mg·kg⁻¹ in May, June, and July, respectively, which showed a downtrend. The period from May to July is the midseason growth period of *L. chinensis*, and roots absorb large quantities of Zn from the soil. With the temperature increasing from May to July, the decomposition rate of microorganism accelerated, however it was lower than the absorption rate of roots. Therefore, the content of Zn declined. After July, abundant rainfall and higher temperatures promoted the decomposition of microorganisms, and the growth of *L. chinensis* gradually stopped since August with a great deal of litter appeared. Therefore the average content of total Zn in the soil increased from August to October, which was separately 32.04 mg·kg⁻¹, 33.05 mg·kg⁻¹, and 33.82 mg·kg⁻¹. The content of Zn in the soil was higher in October than in May, but there was no significant difference between the two months ($P>0.05$).

Total Zn content measured for every month was also the highest in the 0–1 cm soil layer, with an average of 47.56 mg·kg⁻¹. The content of total Zn reduced as increase of the depth of soil. The average content of total Zn in the layers of 1–10 cm, 10–20 cm, 20–30 cm, 30–40 cm and 40–50 cm were 40.48 mg·kg⁻¹, 32.40 mg·kg⁻¹, 26.32 mg·kg⁻¹, 25.87 mg·kg⁻¹, and 25.29 mg·kg⁻¹, respectively. The content of Zn was the lowest in the 40–50 cm soil layer. Differences of total Zn content were not significant ($P>0.05$) between 20–30 cm, 30–40 cm and 40–50 cm. The average content of total Zn was up to 30.33 mg·kg⁻¹ in the 50–60 cm layer. This is due to the fact that the ore of Zn could be effloresced to fine-grained soil and easily deposited in deeper soil, and the eluviations as the rainy season approached.

Average content of total Zn in the soil is 32.61 mg·kg⁻¹, which is much lower than the countrywide level of 68.0 mg·kg⁻¹ and the worldwide level of 50 mg·kg⁻¹ (Liu 1991).

Spatio-temporal dynamic of available Zn in the soil and the correlation analysis

Spatio-temporal dynamic of available Zn in the soil

The dynamic trend of available Zn content in the soil was similar to that of total Zn content, with a sharply downtrend from 0–1 cm to 50–60 cm (Fig. 2).

Average content of available Zn gradually declined from May to July, which was separately 1.415 mg·kg⁻¹, 1.222 mg·kg⁻¹, and 0.982 mg·kg⁻¹, then it went up to 1.03 mg·kg⁻¹ in August due to the fact that abundant rainfall and high temperature accelerated the decomposition activities of microorganisms, at the same time, the growth of *L. chinensis* became slower. Compared with the total Zn content, the content of available Zn declined from September (0.846 mg·kg⁻¹) to October (0.662 mg·kg⁻¹). This is mostly due to the fact that the decreasing temperatures can decrease the activity of available Zn (Yuan 1983). Lower temperature can also depress the activities of microorganisms and reduce the decomposition of organic matter. The difference of available Zn content was significant from May to October ($P<0.05$).

In the 0–1 cm soil layer, average content of available Zn for every month was 2.726 mg·kg⁻¹, which was significantly higher than that in other layers ($P<0.01$). This phenomenon was because well-solved zinc acid radical could be formed easily in the high Na⁺ alkaline soil, and the content of organic matter was high and the pH was low in this layer of natural grassland. These factors can also help to increase the content of available Zn. Average contents of available Zn in layers 1–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, 40–50 cm, and 50–60 cm were 1.47 mg·kg⁻¹, 1.00 mg·kg⁻¹, 0.63 mg·kg⁻¹, 0.47 mg·kg⁻¹, 0.43 mg·kg⁻¹, and 0.45 mg·kg⁻¹, respectively. There was no significant difference in available Zn contents among the soil layers of 30–40 cm, 40–50

cm, and 50–60 cm ($P>0.05$).

The average content of available Zn was $1.472 \text{ mg}\cdot\text{kg}^{-1}$ in the soil of Northeast *L. chinensis* grassland, which was moderate

compared with the $1.1\text{--}2.0 \text{ mg}\cdot\text{kg}^{-1}$ of average range in China (Yuan 1983).

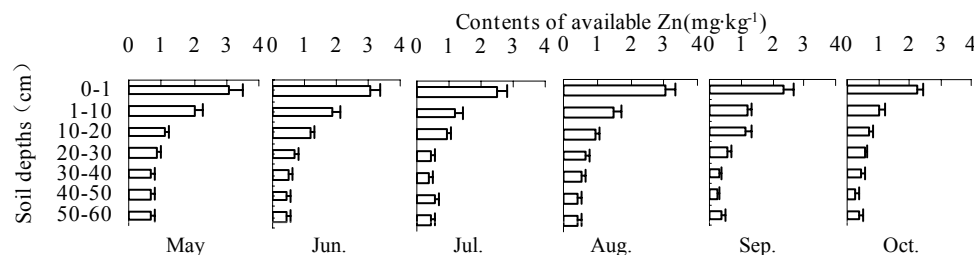


Fig.2 Spatio-temporal dynamic of available Zn content in the soil

Correlation analysis between the content of available Zn in soil and environmental factors

An analysis on the content of available Zn, and the pH in each layer of soil, showed that there was a significant negative linear correlation between them ($r=-0.9621$, $p<0.01$) (Fig. 3). The content of available Zn decreased by $1.944 \text{ mg}\cdot\text{kg}^{-1}$ for increasing per one unit of pH. The reason is that there are so many kinds of compounds involving Zn and their solubilities are affected most by the acidity. Solubility of the compounds declined with pH level increasing, which made the content of available Zn decline. Furthermore, the absorption of Zn in soil was also related to the pH. High pH in the soil could weaken the competition of H^+ , so the soil could absorb more Zn, and then reduce the content of available Zn. In addition, an increase in pH could promote the complex of soluble Zn, and reduced the content of available Zn.

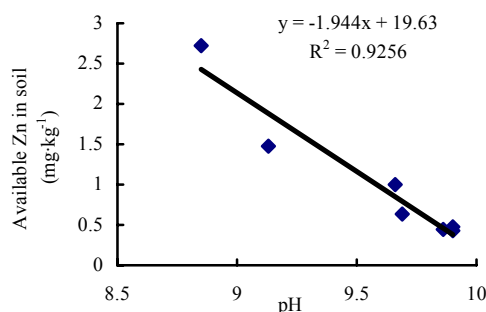


Fig. 3 Correlation analyses on the content of available Zn and the pH in each layer of soil

Correlation analysis on the content of available Zn and the organic matter in each layer of soil showed a significant positive linear relation ($r=0.9429$, $p<0.01$) (Fig. 4). The content of available Zn increased by $0.1055 \text{ mg}\cdot\text{kg}^{-1}$ as increased $1 \text{ g}\cdot\text{kg}^{-1}$ organic matter. This is because the complex of organic matter and Zn was good for keeping Zn in a soluble state. Results showed that the content of Zn in the plants was in the order of roots>rhizomes>leaves>stems>litter (Fig. 5). Average content of those were $48.21 \text{ mg}\cdot\text{kg}^{-1}$, $41.80 \text{ mg}\cdot\text{kg}^{-1}$, $39.16 \text{ mg}\cdot\text{kg}^{-1}$, $38.50 \text{ mg}\cdot\text{kg}^{-1}$, and $37.48 \text{ mg}\cdot\text{kg}^{-1}$, respectively. In the growing season, the dynamic of Zn took on a fluctuating trend whether in the leaves or the stems of *L. chinensis*, and showed the 'V' type curve in the rhizomes, roots and the litter. The content of Zn in plants was in range of $20\text{--}100 \text{ mg}\cdot\text{kg}^{-1}$ (Liu 1991), thus, the

plants is not lack of Zn.

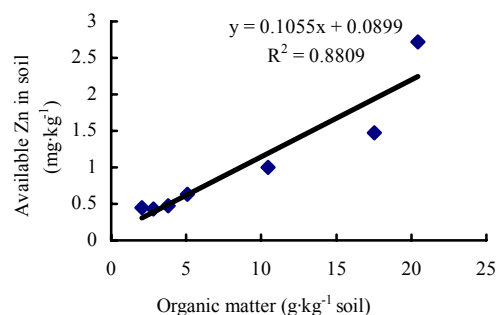


Fig. 4 Correlation analyses on the content of available Zn and the organic matter in each layer of soil

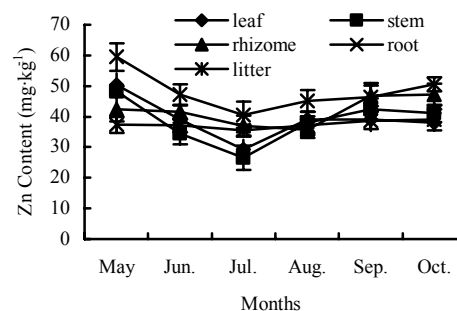


Fig. 5 Seasonal dynamic of Zn in roots, rhizomes, stems, leaves and litter of *Leymus chinensis*

Dynamic of the content of Zn in roots, rhizomes, stems and leaves of *L. chinensis*

In the early of the May, the accumulation of Zn was higher in roots, which is helpful for the transfer of Zn in stems and leaves, and growth of plants as well. Thus, content of Zn was higher in stems and leaves in the earlier part of the growing season. With the rapid growth of *L. chinensis*, Zn absorbed by roots gradually decreased, thus Zn supplement to stems and leaves also declined. Contents of Zn in roots, stems and leaves were the lowest in July. Then in August the growing rate of *L. chinensis* slowed down and the contents of Zn increased. Until September, Zn in stems and leaves began to transfer downwards, and the contents of Zn

in stems and leaves reduced and transferring rate of Zn became slower. Zn reserves in roots reached the peak in October, which can assure the growth of *L. chinensis* in the next year.

The content of Zn in litter was similar to that in live plants. The Zn in litter was also lowest in July, and was higher in October than in May.

Transferring rules of Zn between soil and plants

Table 1 . Seasonal dynamic of the transfer intensity of Zn in the soil and plants

Items	May	Jun.	Jul.	Aug.	Sep.	Oct.	Average value
A layer/B layer (available Zn)	1.85	4.36	3.58	4.26	3.09	2.20	3.06
A layer/B layer(total Zn)	1.44	1.57	1.42	1.23	1.38	1.17	1.37
Activity of Zn in A layer (%)	3.46	5.93	4.97	3.72	2.83	2.47	3.90
Absorption intensity of root	44.17	21.03	23.02	35.08	43.01	57.82	44.17
Intensity of transfer from the belowground to the aboveground	0.97	0.83	0.72	0.96	0.87	0.81	0.86
Intensity of transfer from the aboveground to the litter	0.76	1.01	1.27	0.96	0.95	0.99	0.99

Note: Activity of Zn (%)=(content of available Zn/content of total Zn)×100; Absorption intensity of root=content of Zn in root/ content of available Zn; Intensity of transfer from the belowground organisms to the aboveground organisms =content of Zn in belowground organisms/in aboveground organisms; Intensity of transfer from the aboveground organisms to the litter = content of Zn in litter/ in aboveground organisms.

Discussion

The dynamic of Zn content between the soil and plant was analyzed in detail in the Northeast *L. chinensis* grassland. The nutritional conditions of the trace elements of Zn were investigated. In addition, the mobile rule of Zn in the ecosystem was disclosed by analyzing the intensity of Zn absorption or transfer.

Results showed that the average content of total Zn was lower in the soil of the Northeast *L. chinensis* grassland. The content of trace elements in soil was affected by many factors, but it was mainly affected by the soils parent materials (Xu 2000; Zhang 2002). The soil in the Northeast *L. chinensis* grassland is developed in yellow sand formed by aeolian sand or outwash sand, and the physical clay grain is less than the average in China. The research of Shen (1983) showed that the content of Zn was negative relative to the content of physical gravel in the soil, but significantly more positive relative to the content of soil clay grain ($P<0.01$ mm).

The average content of available Zn was moderate in the soil. In terms of the earlier presumption, the available Zn relied on the supply of total Zn, and the high pH reduced the activity of available Zn in the alkaline soil (Wang 2002), thus, the content of available Zn was relatively low. The distributive rules of total Zn and available Zn, and the effect of environmental factors on content of Zn showed that there were three means to increase effective Zn in nature: (1) Reduction of topsoil pH levels in the natural grassland; (2) Accumulation of organic matter in the topsoil of natural grasslands which promotes the enrichment of Zn; (3) A higher contents of Na and K in the A layer of the serious alkaline-saline soil in the Northeast *L. chinensis* grassland (Ge 1992). Here Zn in the soil tends to form zincate with Na and K. Therefore, available Zn is not in the alkaline-saline soil, and this result had been substantiated by Cai *et al.* (2002) who investigated the vertical divergence of trace element distribution in typical soil of Heilongjiang Province. Effective Zn in the soil is enough to supply *L. chinensis* whose roots were mostly located in the soil layer of 0-20 cm.

The ratio of effective Zn in A layer to that in B layer was more than two times as that of total Zn. This result indicated that the

From Table 1, we can see that activity of Zn in A layer is 3.90%, and the enrichment of Zn in the root of *L. chinensis* is 44.17 times than that in the soil (Table 1).

The transfer of Zn from belowground to aboveground took on a reducing trend from May to July, and then increased in August, subsequently decreased again. The transferring intensity of Zn from aboveground to litter was significantly negative relative to that from belowground to aboveground ($r=-0.8800$, $p<0.01$).

enrichment capacity of effective Zn was stronger in the A layer of soil. The activity of Zn was highest in June, and then gradually declined in July. In October the activity became the lowest, because high temperature and humidity improved the activity of microorganisms in soil and accelerated the decomposition of organic matter. Shuman (1979) has separated Zn from organic matter in 8 kinds of soil, and results showed that content of Zn ranged from 53 mg·kg⁻¹ to 132 mg·kg⁻¹ (Liu 1994). As a result, Zn from organic matter returning to the soil was the most significant way to increase the activity of Zn in the soil.

The root of *L. chinensis* is the absorbing organ of Zn in the soil. Consequently, the capacity of roots to absorb available Zn could represent the capacity of plants absorbing Zn elements. The absorbability of Zn was mainly controlled by active absorption which was relative to metabolism of plants (Liu 1998). The enrichment of Zn in the root of *L. chinensis* was 44.17 times than that in the soil. The absorbing intensity of roots was significantly more negative relative to the activity of Zn in the soil ($r=0.9381$, $P<0.01$).

Zn was mobile in plants (Liu 1991). Roots of *L. chinensis* deposited a lot of Zn in the early of the growing season, and aboveground biomass of *L. chinensis* was less at that time, so a larger quantity of Zn was concentrated and transferred aboveground. Temperature, humidity and the decomposition rate of microorganism were high in June and July, during this period, plants grow rapidly and plenty of nutrition was accumulated in the aboveground plants, thus the transfer of nutrient elements weakened in organisms. The growing rate of *L. chinensis* became slower after August and the upward transfer of nutrient elements was also slower. Therefore, the transfer of Zn in the plants gradually weakened from belowground to aboveground, thus there was more Zn in the belowground organisms again. As a result, the absorbing intensity of roots increased.

Zn moved slowly in the phloem, and was not easy to recycle (Liu1998). Zn rarely transferred from litter to belowground organs of *L. chinensis*. Thus, Zn was deposited in the litter, and the transfer intensity from aboveground organisms to litter even got as high as 0.99.

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